

PROCESS FOR THE PREPARATION OF A METAL-ORGANIC COMPOUND
COMPRISING AT LEAST ONE IMINE LIGAND

The invention relates to a process for the preparation of a metal-organic compound comprising at least one imine ligand according to formula 1. Metal-organic compounds thus produced are typically used as precatalyst in the production of polyolefins. Imine ligands for these precatalyst can be guanidine, iminoimidazoline, or ketimine, the manufacturing of which is described in WO 02070569 and US 6114481 respectively. Two procedures for the preparation of a guanidine or iminoimidazoline comprising metal-organic compound are disclosed in WO 02070569, starting from the respective ligands and CpTiCl_3 .

In the first procedure, the ligand is contacted at -80°C with butyllithium in THF and warmed room temperature. Then, this mixture is further contacted with CpTiCl_3 at -80°C and warmed up to room temperature. After removal of the THF, the metal-organic compound formed is extracted with boiling toluene, followed by its isolation by means of crystallization. The resulting product is further benzylated in a subsequent reaction step.

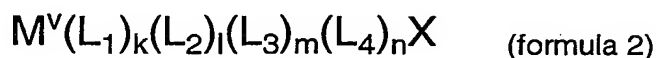
In the second procedure CpTiCl_3 is contacted with 3 equivalents of benzylmagnesiumbromide (BzMgBr) in diethylether at 0°C . After warming up to room temperature and stirring for 12 hours, the thus formed CpTiBz_3 was extracted and subsequently crystallized. Then CpTiBz_3 was contacted with the iminoimidazoline ligand in toluene at 50°C for 2 hours. The metal-organic compound obtained, was isolated after crystallization from boiling hexane. A disadvantage of this process is that at least two steps are required, which have to be carried out at low temperature and require some solvent changes.

Purpose of the present invention is to provide a widely applicable method for the manufacturing of a metal-organic compound from an imine and a metal-organic precursor in one step.

This aim is achieved in that an imine ligand according to formula 1, or the HA adduct thereof, wherein HA represents an acid, of which H represents its proton and A its conjugate base, is contacted with a metal-organic reagent of formula 2 in the presence of at least 1, respectively 2 equivalents of base, wherein



wherein Y is selected from a substituted carbon, or nitrogen atom and R represents a
 5 proton, a protic or an aprotic substituent, and:



wherein:

10 M represents a group 4 or group 5 metal ion

V represents the valency of the metal ion, being 3, 4 or 5

L₁, L₂, L₃, and L₄ represent ligands on M and may be equal or different

X represents a group 17 halogen atom

k, l, m, n = 0, 1, 2, 3, 4 with k+l+m+n+1=V

15 With the method of the invention a metal-organic compound, suitable as precatalyst in olefin polymerisation, is prepared in one step. An additional advantage of the method of the invention is, that during the process hardly any by-products are formed, so that further purification is not necessary (or very limited with respect to state of the art processes). The metal-organic compound prepared by the method of the
 20 invention has a higher purity than a metal-organic compound prepared via known production processes and can be used as such in olefin polymerisation processes. An additional advantage of the process of the invention is that the process can be carried out at room temperature, whereas the reaction of the N-trialkylsilyl substituted imine ligand with the metal-organic reagent has to be often carried out at elevated
 25 temperatures.

The imine derivative or its HA adduct, as represented in formula 1, is substituted by an Y-and an R group. In the method of the invention, the Y group consists of a substituted carbon, or nitrogen atom. If Y represents a substituted carbon atom, the number of substituents is 2. If Y represents a substituted nitrogen atom, the
 30 number of substituents is 1

Substituents on carbon, or nitrogen may be equal or different, optionally linked with each other, optionally having heteroatoms. Substituents may be protic or aprotic. A protic substituent is defined here as a substituent, which has at least one, group 15 or group 16 atom containing at least one proton.

Examples of protic substituents include C₁-C₂₀ linear, branched or cyclic hydrocarbyl radicals, substituted with a group 15 or 16 atom bearing at least one hydrogen atom. Preferred protic substituents include phenolic radicals, pyrrolic radicals, indolic radicals, and imidazolic radicals.

5 The substituent is called aprotic if the substituent lacks a group containing a group 15 or group 16 atom bearing a proton. An unsubstituted aprotic hydrocarbyl radical can be a C₁-C₂₀ linear, branched or cyclic radical, a hydrogen atom, a halogen atom, a C₁₋₈ alkoxy radical, a C₆₋₁₀ aryl or aryloxy radical, an amido radical, or a C₁₋₂₀ hydrocarbyl radical unsubstituted or substituted by a halogen atom, a
10 C₁₋₈ alkoxy radical, a C₆₋₁₀ aryl or aryloxy radical, an amido radical, a silyl radical, or a germanyl.

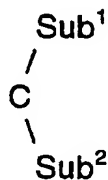
The substituent R can be H, or being equal as these for the substituent on Y.

15 Examples of imine ligands according to formula (1) thus include: guanidines, iminoimidazolines, phosphinimines, phenolimines, pyrroleimines, indoleimines and imidazoleimines.

R may be linked with Y, thus forming a ring system, optionally comprising heteroatoms, or optionally comprising functional groups. Examples of ligands comprising such ring systems include: 8-hydroxyquinoline, 8-aminoquinoline, 8-
20 phosphinoquinoline, 8-thioquinoline, 8-hydroxyquinaldine, 8-aminoquinaldine, 8-phosphinoquinaldine, 8-thioquinaldine and 7-azaindole or indazole.

In a preferred embodiment of the method of the invention, R represents a hydrogen atom and Y is selected from the group consisting of: a substituent according to formula 3:

25



(formula 3)

30 wherein each of Sub¹ and Sub² is independently selected from the group consisting of hydrocarbyl radicals having from 1 to 30 carbon atoms; silyl radicals, (substituted) amido radicals and (substituted) phosphido radicals, and wherein Sub¹ and Sub² may

be linked with each other to form a ring system.

Preferably Sub¹ and Sub² are each independently selected from the group of C₁-C₂₀ hydrocarbyl radicals, or substituted amido radicals optionally linked by a bridging moiety.

5 In the process of the invention, HA represents an acid, of which H represents its proton and A its conjugate base. Examples of A are halogenides, such as fluoride, chloride, bromide, or iodide, sulfate, hydrogensulfate, phosphate, hydrogenphosphate, dihydrogenphosphate, carbonate, hydrogencarbonate, aromatic or aliphatic carboxylates, cyanide, tetrafluoroborate, (substituted) tetraphenylborates,
10 fluorinated tetraarylborates, alkyl or aryl sulfonates.

The "number of equivalents of a base" is understood to be the amount of equivalents with respect to the number of imine ligands, or functionalities in the event that one ligand comprises more than one imine functionality. With "at least 1, respectively 2 equivalents of a base", and later on in the application "at least 3,
15 respectively 4 equivalents of a base", is meant that at least 1, respectively 3 equivalents of a base are required when the imine ligand as such is used, but that at least 2, respectively 4 equivalents are required, in case the HA adduct of the imine ligand is used.

The metal-organic reagent used in the method of the invention is a
20 reagent according to formula 2. In this formula L₁ to L₄ can independently be a monoanionic ligand or a group 17 halogen atom.

Examples of monoanionic ligands are: halides like a fluoride, chloride, bromide or iodide, (un)substituted aliphatic or aromatic hydrocarbyls, like C₁-C₂₀ hydrocarbyl radicals, aryloxy or alkyloxy, cyclopentadienyls, indenyls,
25 tetrahydroindenyls, fluorenyls, tetrahydrofluorenyls, and octahydrofluorenyls, amides, phosphides, sulfides, ketimides, guanidines, iminoimidazolines, phosphinimides, substituted imines, like (hetero)aryloxyimines, pyrroleimines, indoleimines, imidazoleimines or (hetero)aryloxides.

Preferred monoanionic ligands include: fluoride, chloride, bromide,
30 iodide, C₁-C₂₀ hydrocarbyl radicals, cyclopentadienyl, C₁-C₂₀ hydrocarbyl substituted cyclopentadienyls, halogen substituted C₁-C₂₀ hydrocarbyl substituted cyclopentadienyls, indenyl, C₁-C₂₀ hydrocarbyl substituted indenyls, halogen substituted C₁-C₂₀ hydrocarbyl substituted indenyls, fluorenyls, C₁-C₂₀ hydrocarbyl substituted fluorenyls, halogen substituted C₁-C₂₀ hydrocarbyl substituted fluorenyls,
35 C₁-C₄₅ substituted phosphinimides, C₁-C₂₀ substituted ketimides, C₁-C₃₀ substituted

guanidines, C₁-C₃₀ iminoimidazolines.

Most preferably monoanionic ligands are selected from fluoride, chloride, bromide, iodide, cyclopentadienyl, C₁-C₂₀ hydrocarbyl (optionally containing hetero- or group 17 halogen atoms), substituted cyclopentadienyls, indenyl, C₁-C₂₀ hydrocarbyl substituted indenyls, and halogen substituted C₁-C₂₀ hydrocarbyl substituted indenyls.

Depending on the valency of the metal of the metal-organic reagent, preferably at least one L₁, L₂, L₃, or L₄ represents a group 17 atom. If the valency of the metal V = 3, one or two ligands L may represent a group 17 atom. If V = 4, two or three ligands L may represent a group 17 atom. If V = 5, two to four ligands L may represent a group 17 atom. Preferred group 17 atom ligands are fluoride, chloride, bromide or iodide atoms. The most preferred group 17 atom ligand is chloride. In a most preferred embodiment, at least one of the ligands L is chosen from cyclopentadienyl, C₁-C₂₀ hydrocarbyl (optionally containing hetero- or group 17 halogen atoms), substituted cyclopentadienyls, indenyl, C₁-C₂₀ hydrocarbyl substituted indenyls, and halogen substituted C₁-C₂₀ hydrocarbyl substituted indenyls. C₁-C₂₀ hydrocarbyl (optionally containing hetero- or group 17 halogen atoms) also includes aryloxy or alkyloxy, octahydrofluorenyls, amides, phosphides, sulfides, ketimides, guanidines, iminoimidazolines, phosphinimides, substituted imines, like (hetero)aryloxyimines, pyrroleimines, indoleimines, imidazoleimines and (hetero)aryloxides.

In the method of the invention an imine ligand or the HA adduct thereof according to formula 1, is contacted with a metal-organic reagent of formula 2 in the presence of at least 1, respectively 2, equivalents of a base. Examples of a base include, carboxylates (for example potassium acetate), fluorides, hydroxides, cyanides, amides and carbonates of Li, Na, K, Rb, Cs, ammonium and the group 2 metals Mg, Ca, & Ba, the alkali metal (Li, Na, K, Rb, Cs) phosphates and the phosphate esters (eg. C₆ H₅ OP(O)(ONa)₂ and related aryl and alkyl compounds) and their alkoxides and phenoxides, thallium hydroxide, alkylammonium hydroxides and fluorides. Some of these bases may be used in conjunction with a phase transfer reagent, such as for example tetraalkylammonium-, tetraalkylphosphonium salts or crown ethers. Also stronger bases may be applied, like carbanions such as hydrocarbanions of group 1, group 2, group 12 or group 13 elements. Also the metallic alkalimetals of group 1 may be applied as a base.

Preferred bases include amines, phosphanes, organolithium compounds, or organomagnesium compounds, alkali metals, group 1 hydrides or

group 2 hydrides

More preferred bases are mono-, di-, or tri-, alkylamines or aromatic amines, organolithium compounds, organomagnesium compound, sodium hydride or calciumhydride. Under aromatic amines is understood in this application compounds
5 having a nitrogen atom in an aromatic ring system or mono-, di-, or triarylamines.

Even more preferred bases are triethylamine, pyridine, tripropylamine, tributylamine, 1,4-diaza-bicyclo[2.2.2]octane, pyrrolidine or piperidine organolithium compounds, or organomagnesium compounds. Examples of organomagnesium compounds are: methylmagnesiumhalides,
10 phenylmagnesiumhalides, benzylmagnesiumhalides, biphenylmagnesiumhalides, naphthylmagnesiumhalides, tolylmagnesiumhalides, xylylmagnesiumhalides, mesitylmagnesiumhalides, dimethylresorcinolmagnesiumhalides, N,N-dimethylanilinemagnesiumhalides, dimethylmagnesium, diphenylmagnesium, dibenzylmagnesium, bis(biphenyl)magnesium, dinaphthylmagnesium, ditolylmagnesium,
15 dixylylmagnesium, dimesitylmagnesium, bis(dimethylresorcinol)magnesium, bis(N,N-dimethylaniline)magnesium.

Examples of organolithium compounds are: methyllithium, phenyllithium, benzyllithium, biphenyllithium, naphthyllithium, dimethylresorcinollithium, N,N-dimethylanilinellithium.

20 In order to make a polyolefin by a borane or borate activatable metal-organic compound, the halide groups of the metal-organic compound from the process of the invention have to be alkylated or arylated in an additional reaction step. This can be done for example with an organolithium compound or an organo-magnesium compound. Surprisingly it has been found that such alkylated or arylated metal-organic
25 compound can also be prepared in one step by the process of the invention by carrying out the process in the presence of at least 3, respectively 4 equivalents of an organomagnesium compound or an organolithium compound as a base. This holds for a metal-organic reagent comprising 3 halogen ligands reacting with 1 imine functionality only. One skilled in the art will understand that metal-organic reagents with
30 4 or 5 halogen ligands will require at least 4 respectively 5 equivalents of a base in stead of at least 3; or 5 respectively 6 equivalents in stead of 4.

The process of the invention is preferably carried out in a solvent. Suitable solvents are solvents that do not react with the metal-organic reagent or the metal-organic compound formed in the process of the invention. Examples of suitable
35 solvents include aromatic and aliphatic hydrocarbons, halogenated hydrocarbons,

amides of the aliphatic carboxylic acids and primary, or secondary amines, DMSO, nitromethane, acetone, acetonitrile, benzonitrile, ethers, polyethers, cyclic ethers, lower aromatic and aliphatic ethers, esters, pyridine, alkylpyridines, cyclic and primary, secondary or tertiary amines, and mixtures thereof. Preferred solvents include aromatic
5 or aliphatic hydrocarbons or mixtures thereof.

The process of the invention can be carried out, by adding at least 1, respectively at least 2 equivalents of a base to a mixture of the imine ligand or its HA adduct and the metal-organic reagent thus forming a reaction mixture. The desired metal-organic compound is often formed instantaneously. Excess of a base may be
10 applied without negative effects on the reaction product. The process of the invention is preferably carried out in the presence of 1 equivalent of a base with respect to the imine ligand, or 2 equivalents in the event that the HA adduct of the imine ligand is used. Surprisingly it turned out that the reaction even with only one equivalent of an organic base appeared to be instantaneously at room temperature to quantitative
15 conversion. Another advantage of a process of the invention in the presence of only one equivalent of a base, is that the resulting compound may have a higher activity. Without being bound to an explanation, this may be a consequence of the fact that the formation of a coordination complex of the organic base with the metal-organic compound is prevented.

During the reaction, a salt is formed. The reaction mixture as obtained by contacting an imine or its HA adduct with a metal-organic reagent in the presence of a base, may be used as precatalyst in a polyolefin polymerisation without an additional purification step if the salt formed during the reaction is compatible with the polymerisation process. A purification step is understood to be a filtration, a
25 crystallization or a precipitation. Preferably the purification is a filtration step. If a salt free metal-organic compound is required, the salt can be removed by using a filtration step. Depending on the solubility of the metal-organic compound, the mixture may be heated and then filtered. An advantage of the present invention is that the filtrate may be used as such without further purification in a following process, such as an
30 alkylation or arylation step or the polymerisation process. If desired, the metal-organic compound may be isolated by distillation of the solvent, by precipitation or by crystallisation from a suitable solvent.

The invention further relates to a process for the preparation of a polyolefin as described in claim 13. Such an olefin polymerisation can be carried out in
35 solution, slurry or in the gas phase.

In a preferred embodiment of the olefin polymerisation the (alkylated) metal-organic compound is formed in situ. By in situ preparation is meant in this context, that the metal-organic compound is made and subsequently activated in or anywhere before the reactor of the polymerisation equipment by contacting an imine or its HA adduct with an metal-organic reagent in the presence of an olefin polymerisation compatible base. In the in situ preparation of the metal-organic compound, it turned out to be favourable to use a surplus of ligand. The number of ligands which are effectively bound to the metal ion are then determined by the number of equivalents of the base. In this case the "number of equivalents of a base" should then be read as the number of equivalents of a base with respect to the equivalents of the ligands being bound to the metal ion. Examples of bases compatible with the olefin polymerisation process include amines, organomagnesium compound, organolithium reagents, organozinc reagents, organoaluminum reagents. More preferred bases are: aromatic amines, organomagnesium compound, organolithium reagents, organozinc reagents, organoaluminum reagents. Most preferred bases are N,N-dimethylaniline, diphenylmethylamine, triphenylamine, dibutylmagnesium, n-butyllithium, C₁-C₂₀ dihydrocarbylzinc derivatives, diisobutylaluminium hydride, C₁-C₂₀ trihydrocarbyl aluminiums, or aluminoxanes. In the case where aluminoxanes are applied as a base, the base can be the activator.

In the olefin polymerisation according to the invention, R preferably represents a hydrogen atom and Y is preferably a substituent according to formula 3 of claim 2.

Advantages of the process of the invention are: mild conditions, avoidance of (ultra) cooling steps, higher yields, higher reaction rates and smaller amounts of by-products. The (alkylated) metal-organic compounds as obtained by the invented process can be used without further purification in the olefin polymerisation resulting in more active catalysts.

The invention will be elucidated with some non-limiting examples:

General part

Experiments were performed under a dry and oxygen-free nitrogen atmosphere using Schlenk-line techniques. ¹H-NMR and ¹³C-NMR-spectra were measured on a Bruker Avance 300 spectrometer. Diethyl ether and ligroin were distilled from sodium/potassium alloy; THF and toluene from potassium and sodium, respectively, all having benzophenone as indicator.

Tri-ethylamine was distilled from calciumhydride before use.

Other starting materials were used as obtained.

Part A Examples related to the preparation of the preparation of the metal-organic compound.

Example I. Synthesis of 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline cyclopentadienyl titanium dichloride

To a suspension of 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline (1.50 g, 5.0 mmol) (prepared according to the procedure by L.Toldy et al, US Patent 4,284,642), and cyclopentadienyltitanium trichloride (1.10 g, 5 mmol) in toluene (80 mL) was added triethylamine (1.0 mL, 7.2 mmol) at ambient temperature. After stirring for 1 hour, the suspension was heated to reflux, then filtered hot. Cooling to ambient temperature gave orange crystals, which were filtered, washed with cold toluene and dried (1.36 g, 57% yield). Partial evaporation of the mother liquor and cooling to -20 °C afforded another 0.90 g (38%). Total yield of 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline cyclopentadienyl titanium dichloride was 95%.

Example II. Synthesis of 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline cyclopentadienyl titanium dimethyl

To a suspension of 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline (5.86 g, 20.0 mmol) and cyclopentadienyltitanium trichloride (4.39 g, 20.0 mmol) in toluene (200 mL) was added triethylamine (2.53 g, 25 mmol) at ambient temperature. After stirring for 1 hour at ambient temperature, the thick yellow-orange suspension was heated to reflux and filtered hot. The yellow residue was extracted with boiling toluene portions of 10 mL 4 times (leaving a grey-white residue). The combined orange filtrates (separating yellow-orange crystals upon cooling) were cooled to 0°C. Methyl magnesium bromide (14 mL of a 3.0 M solution in diethyl ether, 44 mmol) was added in 10 minutes. The orange suspension turned yellow gradually. The mixture was stirred overnight, then evaporated to dryness. The residue was extracted with boiling ligroin (200 mL) and the resulting suspension was filtered hot. Cooling to approx. -20°C afforded yellow crystals, which were filtered and washed with cold ligroin to give 2.8 g (32% yield) of NMR pure product. From the partially evaporated mother liquor and 2nd ligroin extract, a 2nd fraction of pure product was obtained (1.0 g, 11%). Total yield of 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline cyclopentadienyl titanium dimethyl was

43%.

Example III. Synthesis of 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline
cyclopentadienyl titanium dimethyl using methylmagnesium bromide as base.

5 To a suspension of 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline
(2.93 g, 10.0 mmol) and cyclopentadienyltitanium trichloride (2.19 g, 10.0 mmol) in
toluene (100 mL) was added methylmagnesiumbromide (11 mL of a 3.0 M solution in
diethyl ether, 33 mmol) at -80°C during 10 minutes. The mixture was allowed to warm
to ambient temperature to give a yellow suspension. THF (30 mL) was added, and the
10 mixture was stirred for 15 hours. The light yellow suspension was evaporated to
dryness. The residue was extracted with boiling ligroin (100 mL). The resulting
suspension was filtered hot. The cake was extracted further with hot ligroin (Three
times with 60 mL until the filtrate became colourless). The combined yellow filtrates
were partially evaporated under reduced pressure to 50 mL. Cooling to approx. 4°C
15 afforded yellow crystals, which were filtered and washed with cold ligroin to give 2.05 g
(47% yield) of NMR pure 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline
cyclopentadienyl titanium dimethyl.

Example IV. Synthesis of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline
cyclopentadienyl titanium dichloride

20 a. *Synthesis of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline*

To a mixture of 2,6-diisopropylaniline (260 g, 1.47 mol) in ethanol (1200 mL) was
slowly added glyoxal (108.5 g of a 40 w-% in water solution, 0.75 mol). The
solution turned intensely red, then intensely yellow. The mixture was heated to
25 reflux overnight. Cooling to 4 degrees resulted in crystallisation of yellow material,
which was filtered and washed with cold ethanol until filtrate became bright yellow
(instead of brown). The bright yellow powder was dried (202.6 g, 72%). This
diimine (100 g, 0.27 mol) was dissolved in ethanol (1000 mL). The mixture was
cooled to 0°C. Sodium borohydride (102.1 g, 2.7 mol) was added in portions during
30 1 hour. The mixture was allowed to warm to room temperature, then stirred 1 hour.
The mixture was heated to reflux gently (gas evolution!) and heated to reflux for 1
hour. After cooling, the mixture was admixed with water (2L), and the suspension
filtered. The yellow precipitate was dried (100.1 g, 98%).
57 g (0.15 mol) of the diamine was dissolved in toluene (250 mL) and heated to
35 reflux. A solution of cyanogen bromide (19.1 g, 0.18 mol) in toluene (100 mL) was

added during the course of ~1 hour, resulting in formation of a grey precipitate in an orange-red solution. After stirring at reflux for 1 hour, the mixture was cooled. The precipitate was filtered, washed with toluene and ligroin (to give 47.1 g yellow light powder). This powder was dissolved in water/ethanol 400/500 mL, and 10.0 M NaOH in water was added until strongly basic (pH>10). The precipitate was filtered and washed with water, then dried to give 37.3 g (61.4% yield) of near pure product. The iminoimidazoline can be crystallized to give pure material as colourless crystals from boiling ligroin (270 mL) and filtering hot to remove some insoluble material (recovery 67%).

10 b. *Synthesis of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline cyclopentadienyl titanium dichloride*

To a suspension of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline (1.02 g, 2.5 mmol) and cyclopentadienyltitanium trichloride (0.55 g, 2.5 mmol) in toluene (20 mL) was added triethylamine (0.4 mL, 4.0 mmol) at ambient temperature. After stirring for 2 hours, the thick yellow-orange suspension was filtered, and the filtrate evaporated to dryness to afford 1.31 g (89% yield) of NMR-pure 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline cyclopentadienyltitanium dichloride.

15 c. *Synthesis of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline cyclopentadienyl titanium dichloride (reversed addition)*

20 The same result as under b. was obtained when cyclopentadienyltitanium trichloride and triethylamine were admixed in toluene, and then ligand was added.

d. *Synthesis of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline cyclopentadienyl titanium dichloride*

To a suspension of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline (2.03 g, 5.0 mmol) and cyclopentadienyltitanium trichloride (1.10 g, 5.0 mmol) in toluene (30 mL) was added triethylamine (0.8 mL, 5.7 mmol) at ambient temperature. After stirring for 1 hour, the thick yellow-orange suspension was diluted with toluene (50 mL) and ligroin (120 mL). The suspension was heated to reflux and filtered hot. Cooling to approx. 4°C afforded yellow crystals, which were filtered and washed with cold ligroin to give 1.34 g (46% yield) of NMR pure 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline cyclopentadienyl titanium dichloride.

Example V. Synthesis of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline cyclopentadienyl titanium dimethyl

35 To a suspension of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline

(2.06 g, 5.0 mmol) and cyclopentadienyltitanium trichloride (1.10 g, 5.0 mmol) in toluene (40 mL) was added triethylamine (0.8 mL, 5.7 mmol) at ambient temperature. After stirring for 2 hours, the thick yellow-orange suspension was filtered, and the residue washed with toluene. The clear and orange filtrate was partially evaporated (~10 mL solvent removed). After cooling to -78 °C (dry ice/acetone), methyl magnesium bromide solution (3.3 mL of a 3M solution in diethyl ether, 10.0 mmol) was added. The temperature of the mixture was allowed to rise to ambient temperature and the mixture was stirred overnight. The yellow suspension was evaporated to dryness. The residue was extracted with boiling ligroin (80 mL) and the resulting suspension was filtered hot. Evaporation to ~30 mL and cooling to approx. 4°C afforded yellow crystals, which were filtered and washed with cold ligroin to give 1.38 g (51% yield) of NMR pure product. From the partially evaporated mother liquor, a 2nd fraction of pure 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline cyclopentadienyl titanium dimethyl was obtained (0.58 g, 19%). Total yield of 1,3-bis(2,6-diisopropylphenyl)-iminoimidazoline cyclopentadienyl titanium dimethyl: 70%.

Example VII. Synthesis of Bis(1-N-cyclohexylcarboximino-6-t-butylphenoxy)titaniumdichloride

To a solution of titanium(IV)chloride (5mL, 1.0M in toluene, 5.0 mmol) in toluene (40 mL) was added 1-N-cyclohexylcarboximine-6-t-butylphenol (2.59g, 10.0 mmol) and triethylamine (1.02g, 10 mmol) subsequently. The reaction mixture was stirred for 16 hours at room temperature. The solid was allowed to precipitate and the supernatant was decanted. The remaining solid was extracted twice with a mixture of toluene/THF (80 mL, 1/1, V/V). The solvents were removed in vacuo resulting in 2.80g (88%) of a red solid. NMR data were consistent with those reported in EP0874005, but the yield of 88 % is substantially higher than the 18 % yield reported in EP 0874005.

Example VIII. Synthesis of Bis(1-N-cyclohexylcarboximino-6-t-butylphenoxy)zirconiumdichloride

To zirconium(IV)chloride (1.40g, 4.5 mmol) was added THF(40mL). The mixture was cooled to 0°C and a solution of 1-N-cyclohexylcarboximine-6-t-butylphenol (2.31g, 8.9 mmol) in toluene (25 mL) was added. Then, triethylamine (0.89 g, 8.9 mmol) was added and the mixture was stirred for 15 hours at room temperature. The solids were allowed to precipitate and the supernatant was decanted from the solid. The solid was extracted with a mixture of toluene/THF (80 mL, 1/1, V/V). The

combined extracts were evaporated to dryness resulting in 2.95g (97%) of a light yellow powder. NMR data were consistent with those reported in EP0874005, but the yield was significantly higher than the yield of 43 % reported in EP 0874005.

5 Part B Examples related to the polymerisation of an olefinic copolymer.

Polymerisation equipment.

The batch copolymerisation was carried out in a polymerisation equipment, having a catalyst dosing vessel equipped with a catalyst dosing pump for the addition of the catalyst to a 2-liter batch autoclave equipped with a double intermig stirrer and baffles. The reactor temperature was controlled by a Lauda Thermostat. The feed streams (solvents and monomers) were purified by contacting them with various absorption media as is known in the art. During polymerisation, the ethylene (C2) and propylene (C3) were continuously fed to the gas cap of the reactor. The pressure of the reactor was kept constant by means of a back-pressure valve.

Copolymerisation experiments.

In an inert atmosphere of nitrogen, the reactor was filled with pentamethylheptanes (PMH) (950 mL) and an amount of MAO (Crompton 10wt% in toluene) and 4-methyl-2,6-di-*tert*-butylphenol (BHT) as given in Tables 1 and 2. The reactor was heated to 90 °C, while stirring at 1350 rpm. The reactor then was pressurized to 0.7 MPa and kept under a determined flow of 200 NL/h of ethylene and 400 NL/h of propylene for 15 minutes. Then, the catalyst components were added to the reactor and possible residual material was rinsed with PMH (50 mL) and subsequently fed to the reactor.

When tritylium tetrakis(perfluorophenyl)borate (TBF20) was used, the TBF20 was added directly after the catalyst addition. After 10 minutes of polymerisation, the monomer flow was stopped and the solution was slowly poured into a 2 L Erlenmeyer flask, and dried over-night at 100 °C under reduced pressure.

The polymers were analysed by FT-IR to determine the amount of incorporated C3 and Intrinsic Viscosity being an indication for the average molecular weight.

Polymer analysis.

The amount of incorporated C3 in weight per cents relative to the

total composition, was measured by means of Fourier transformation infrared spectroscopy (FT-IR) according to ASTM D 3900 method A.

The Intrinsic Viscosity (IV) was measured at 135°C in decaline.

5 Examples 2-15: in situ polymerisation

These catalysts were prepared in the polymerisation equipment by adding amounts as depicted in table 1a of toluene solutions of the metal-organic reagent, the ligand and the base successively to the catalyst dosing vessel in toluene (15 mL). After stirring for 5 minutes, the mixture was injected into the polymerisation reactor. Results are shown in Table 1b.

The experiments 2, 5, 12 and 13 were carried out by adding a prepared and purified metal-organic compound to the catalyst dosing vessel, and subsequently fed to the polymerisation reactor.

It can be concluded from the comparison of all experiments with experiment 2, that all in situ prepared catalysts produce copolymers having a higher molecular weight than the copolymer produced with the CpTiCl_3 and the base only, which allows preparation of a polyolefin by just adding a metal-organic reagent, an imine ligand and at least 1 equivalent of a base to the polymerisation equipment.

From Examples 8 and 10 it can be concluded that a process in the presence of between 5 and 10 equivalents of the imine ligand according to formula 1 is mostly preferred.

Table 1a. In situ polymerisations: polymerisation conditions

Example	Metal-organic reagent/compound	Metal-organic compound dosage ($\mu\text{mol Ti}$)	ligand	Ligand dosage (μmol)	Base	Base dosage (μmol)	Activator system	Al/Ti Molar ratio	BF ₂ O/Ti Molar ratio	BHT/Al Molar ratio	Pol. Time (min)
2	CpTiCl ₃	0.75	-	-	Et ₃ N	0.75	MAO/BHT	3000	-	1	10
5	2	0.05	-	-	-	-	MAO/BHT	3000	-	1	10
6	CpTiCl ₃	0.75	L2	1.5	Et ₃ N	0.75	MAO/BHT	3000	-	1	10
7	CpTiCl ₃	0.75	L2	0.75	Et ₃ N	0.75	MAO/BHT	3000	-	1	10
8	CpTiCl ₃	0.75	L2	3.75	Et ₃ N	0.75	MAO/BHT	3000	-	1	10
10	CpTiCl ₃	0.25	L2	2.5	Et ₃ N	0.25	MAO/BHT	3000	-	1	10
11	CpTiCl ₃	0.4	L2	2	Et ₃ N	0.4	MAO/BHT/TBF ₂ O	3000	2	1	3
12	TiCl ₄	5	-	-	Et ₃ N	10	MAO/BHT	250	-	1	10
13	3	5	-	-	-	-	MAO/BHT	250	-	1	10
14	TiCl ₄	5	L3	10	Et ₃ N	10	MAO/BHT	250	-	1	10
15	TiCl ₄	5	L3	10	-	-	MAO/BHT	250	-	1	10

Metal-organic compound 2 = 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline cyclopentadienyl titanium dibenzyl

Metal-organic compound 3 = Bis(1-N-cyclohexylcarboximino-6-t-butylphenoxy)titaniumdichloride

L2 = 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline

L3 = 1-N-cyclohexylcarboximine-6-t-butylphenol

Table 1b. In situ polymerisations: polymerisation results

Example	ΔT (°C)	Yield (g)	residual Ti in polymer (ppm)	Incorpo- rated C3 ⁺ (wt%)	IV (dl/g)
1	0.8	2.93	8.2	41	2.4
2	0.5	2.74	13.1	62	0.96
3	3.5	8.97	5.3	46	Nd
4	1.6	5.34	3.6	42	Nd
5	1.8	6.09	0.4	48	2.77
6	2.0	8.41	4.3	54	2.07
7	0.8	3.76	9.5		
8	4.2	14.37	2.5	51	2.32
10	4.9	19.84	0.6	52	2.29
11	4.4	18.05	1.1	50	
12	0.6	0			
13	1.3	3.55	67.4		1.67
14	1.1	3.18	75.3		1.65
15	1.2	2.89	82.8		1.72

5 Examples 19-20: polymerisation with unpurified 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline cyclopentadienyl titanium dichloride.

Catalyst preparation

10 Cyclopentadienyltitaniumtrichloride (75 mg, 0.34 mmol) and 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline (0.10g, 0.34 mmol) were mixed in toluene (10mL). Triethylamine (34 mg, 0.34 mmol) was added and the reaction mixture was stirred at room temperature for 2 hours.

Polymerisation

15 For the polymerisation an aliquot (0.75 mL) of the mixture obtained above was diluted with toluene (25mL). From this diluted mixture, an aliquot (0.15 mL)

was added to the catalyst dosing vessel containing PMH (15 mL). This mixture was subsequently added to the polymerisation reactor and the catalyst dosing vessel was rinsed with PMH (50 mL). Examples 19 – 20 indicate that polymerisation of olefinic monomers is possible by just adding a mixture of a metal-organic reagent, an imine ligand and at least one equivalent of a base to a polymerisation reactor with olefinic monomers, without the need to firstly purify (i.e. filtrate) a catalyst (i.e. metal-organic compound) from the mixture.

5

Table 2a. Polymerisation with unpurified catalysts: polymerisation conditions

Example	Metal-organic compound	Metal-organic compound dosage ($\mu\text{mol Ti}$)	Activator system	Al/Ti Molar ratio	BF ₂ O/Ti Molar ratio	BHT/Al Molar ratio	Pol. Time (min)
19	5	0.15	MAO/BHT	3000	-	1	10
20	5	0.15	MAO/BHT	3000	-	1	10

Metal-organic compound 4 = triisopropylphosphoraneimido cyclopentadienyl titanium(IV) dichloride

- 5 Metal-organic compound 5 = 1,3-bis(2,6-dimethylphenyl)-iminoimidazoline cyclopentadienyl titanium dichloride

Metal-organic compound 6 = triisopropylphosphoraneimido cyclopentadienyl titanium(IV) dimethyl

10

Table 2b. Polymerisation with unpurified catalysts: polymerisation results

Example	ΔT ($^{\circ}\text{C}$)	Yield (g)	residual Ti in polymer (ppm)	Incorporated C ₃ ⁺ (wt%)	IV (dl/g)
19	4.8	18.75	0.4	501	2.33
20	4.2	16.5	0.4	53	nd